Examples of how significant challenges for high-field dipole design are handled in block-coil designs

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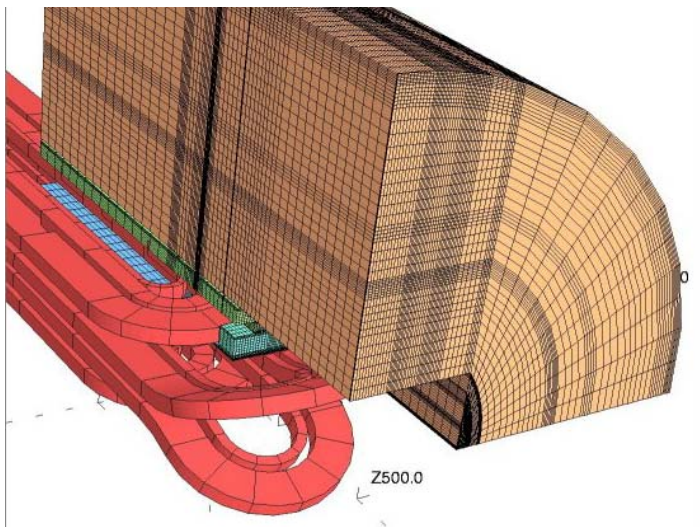
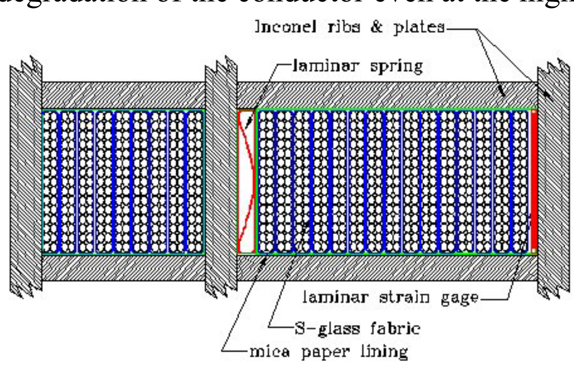
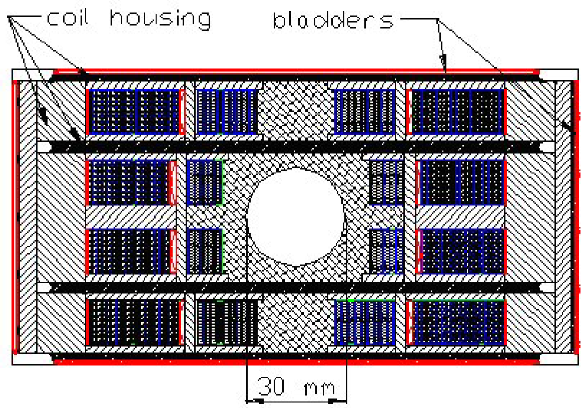
The Texas A&M group is developing a block-coil dipole for future hadron colliders, shown in the figure. The development of this design has led us to devise solutions to several challenges Nb_3Sn collider dipoles: stress management, preload, suppression of snap-back, and cooling of beam-produced heat loads. These solutions make it possible to relax some of the requirements on the conductor that may be helpful in achieving further improvement in current density and reduction of cost.

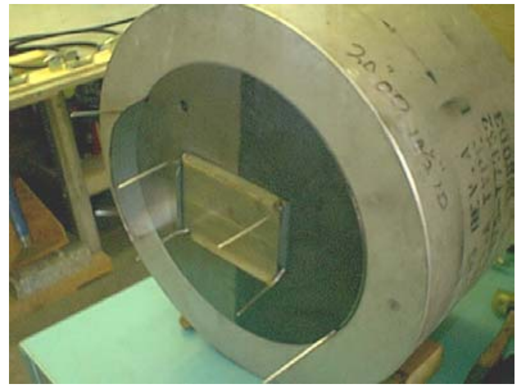


1. *Stress management.* In HD-1, the coil stress reaches ~150 MPa, which is the highest stress level yet achieved in a working coil. In a block coil design it is feasible to off-load Lorentz stress within the windings by introducing a support matrix and a laminar spring, as shown in the figure. This has the advantage of limiting peak stress to any desired value, for example 120 MPa, preventing strain degradation of the conductor even at the highest field strength.



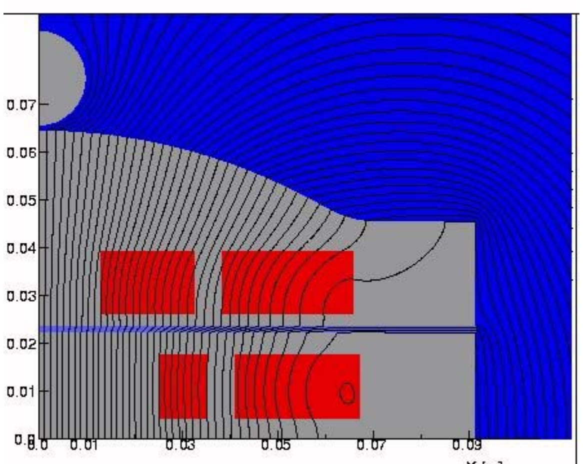
2. *Expansion bladders.* Following the work of Clyde Taylor, expansion bladders can be provided to deliver uniform preload to all boundaries of the coil package. Such an arrangement is shown in the figure. This has the advantage that manufacturing tolerances can be relaxed, shimming is not necessary, and axial preload can be locked in by vertical preload on the windings.

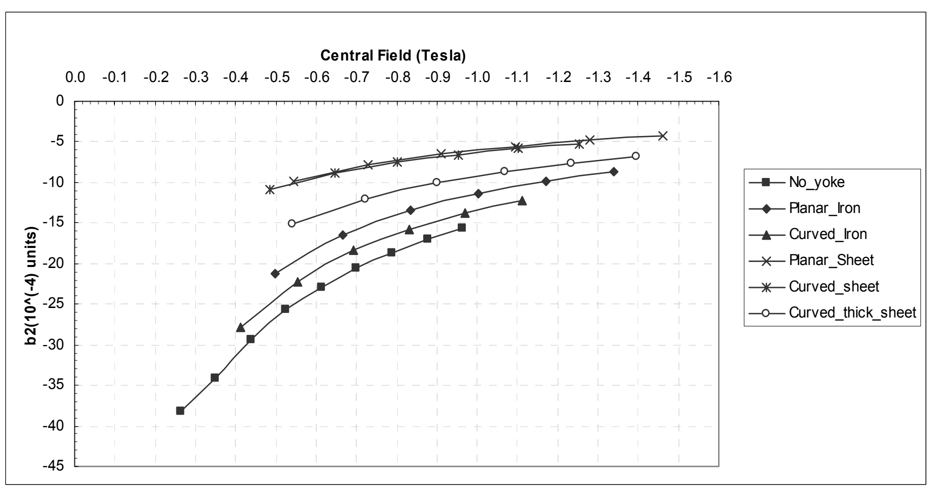




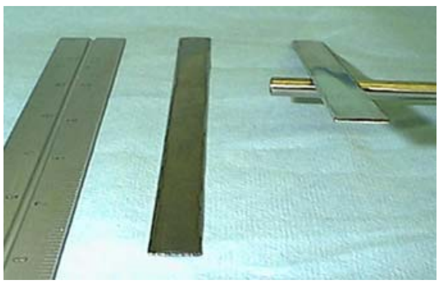
3. *Flux plate suppresses snap-back.* Snap-back is a potentially serious challenge for using Nb_3Sn in collider arc dipoles. As context, LHC's dipoles utilize NbTi with 6 μm filament diameter. In the ramp following injection, snap-back would produce a step change in chromaticity of as much as 70 units, enough to blow away the beam. LHC manages this by careful shaping of the transition to ramp, and by programmed corrections. It is not clear, however, that a much larger snap-back could be corrected. Snap-back scales with filament size, and the currently available filaments of high-performance Nb_3Sn (20 μm for PIT, 100 μm for internal tin) would be workable.

   Persistent multipoles and snap-back can be suppressed in a block-coil design using a magnetic steel flux plate, as shown in the figure. The flux plate is unsaturated at injection, and enforces a dipole boundary closely coupled to the beam tube. A suppression of sextupole by a factor of 3 is calculated, so that 20 μm filaments should be equivalent to the LHC experience.





4. *Laminar springs provide cooling channels*. Heat load from synchrotron radiation and heat and radiation damage from losses pose challenges for Nb_3 dipoles, both in the arcs and for insertion regions. In a block-coil dipole with stress management, a laminar spring is located at the inner bound of each outer winding, as shown in the figure. These springs are hermetically sealed within a stainless steel jacket so that they are not filled with epoxy during impregnation. After impregnation the jackets can be pierced at each end of each spring, providing flow channels for liquid helium to provide cooling within the heart of each winding. Cooling at this location would be most desirable to minimize temperature rise from the above heat sources.



5. *Midplane gap for insertion dipoles*. We have prepared a design of a block-coil dipole, shown below, for the collider arcs of a muon collider, in which a mid-plane gap is opened so that synchtron radiation and decay electrons do not impact the dipole walls. A similar design would facilitate reduction of heat load and radiation damage in a dipole-first design of SLHC.